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14. ABSTRACT
For the initial year of the project new wavelet based signal and image processing algorithms were developed, specifically directed towards usefulness in target recognition applications. Classical spatial and frequency domain image processing algorithms were generalized to process discrete wavelet transform (DWT) data. Results include adaptation of classical filtering, smoothing and interpolation techniques to DWT. From 2003 the research direction changed, in keeping with changes in the direction of ONR's Probability and Statistics Program. A sabbatical leave was devoted to broadening the P.I.'s expertise in aspects of Pattern Recognition. Research was also done on-site at the Naval Surface Warfare Center, Dahlgren, Virginia, where collaborations were formed with NSWC scientists. These resulted, inter alia, in the development of a new tracking algorithm for laser guided weapons. While at NSWC, the P.I. presented tutorial courses and seminars to NSWC scientists. The grant supported 4 graduate students who performed software development and theoretical derivations. During the grant period, 8 peer-reviewed papers were published.

15. SUBJECT TERMS
Target Recognition; Wavelets; Filter Banks; Image Processing; Nonstationarity; Discrete Transforms; Pattern Recognition.

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Final Progress Report on ONR Grant N00014-02-1-0022

Title: **Wavelet-Based Signal and Image Processing for Target Recognition**

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1. Summary

For the initial period of the project (December 2001 to November 2002), the project developed new wavelet based signal and image processing algorithms. These algorithms are specifically directed towards their usefulness in image analysis for target recognition. These algorithms are based upon well known classical spatial-domain and frequency-domain image processing algorithms which are generalized to make them applicable to the processing of discrete wavelet transform (DWT) data. They take advantage of the localization of both frequency and position information provided by the DWT. These results include the adaptation of classical filtering, smoothing and interpolation techniques to the DWT domain.

Towards the end of 2002 a change in the research direction was made, in keeping with a corresponding change in the direction of ONR's Probability and Statistics Program. A sabbatical leave for the Fall of 2003 was devoted to broadening the P.I.'s expertise in aspects of Pattern Recognition. During this period, the following areas were studied in depth: Probability and Statistics, Pattern recognition, Adaptive filtering, Kalman filtering and its extensions, Unscented Transform and Particle filtering, Estimation and tracking, Feature extraction and recognition, Hidden Markov Models. The P.I. gained practical experience in these areas by working in their Signal Processing Laboratory with Drs. Johan Du Preez and Ben Herbst and their Masters and Ph.D. students at the University of Stellenbosch, South Africa.

Much of the research under this grant was done during the abovementioned sabbatical and other visits to the Applied Mathematics and Electrical Engineering Departments

at the University of Stellenbosch. Research was also done on-site at the Naval Surface Warfare Center, Dahlgren, VA. Several collaborations were formed or continued with NSWC scientists, and these produced accomplishments in addition to those proposed in the grant proposal. Most notable is the development of a new tracking algorithm for laser guided weapons, developed with NSWC's Bryan Freeman. Also while at NSWC, the P.I. presented tutorial courses and seminars to NSWC scientists.

The grant supported a total of 4 graduate students who performed software development and some theoretical derivations. During the period of the grant, 8 peer-reviewed papers have been published (1 journal, 6 conferences, 1 conference paper republished in a book).

2. Research Accomplishments:

Where appropriate, a reference is given back to the research proposal. However, because the direction of the research was changed at a relatively early stage of the project, many of the research accomplishments do not directly relate to the original proposal:

1. In collaboration with Bryan Freeman (NSWC, G33), an algorithm was developed that reduces the amount of designation time required for laser-guided weapons, and in addition makes use of the designation information to improve the weapon's estimate of its own absolute position. This algorithm will be presented at the SPIE Defense Security Symposium in Orlando, March 2005.
2. MATLAB software was developed for interpolation of 1-dimensional signals and 2-dimensional images, via the Inverse Wavelet Transform. [Task 1].
3. MATLAB software was developed to implement lowpass, bandpass, and highpass filtering in the Discrete Wavelet Transform domain [Task 3].
4. In collaboration with Marilyn Rudzinski (T44) at the Naval Surface Warfare Center, a wavelet based algorithm was developed for smoothing image sequence data originally obtained for the CRITTIR (Clutter Rejection Involving Temporal Techniques in the Infra-Red) project. The data is obtained from a high frame-rate, high resolution infrared camera, and consists of scenes in which there is considerable interference from the glitter of sunlight on the surface of the sea. [Task 4]
5. In collaboration with Dr. Y.P. Kakad, Professor of Electrical Engineering at UNC-Charlotte, a project is underway to apply independent component analysis to the signals from light-weight MEMS-based optical gyroscopes in order to increase their accuracy. Precision gyroscopes are important in inertial guidance systems for aircraft and missiles, and the aim here is the development of lightweight precision gyroscopes.
6. The P.I. is continuing his collaboration with Dr. Y.P. Kakad (see above) in the hardware implementation of wavelet-based algorithms, and algorithms for fast discrete orthonormal transforms, developed by the P.I. Several publications have resulted from this ongoing collaboration.
7. The P.I. visited the Department of Applied Mathematics at the University of Stellenbosch, South Africa, on sabbatical leave for the Fall 2003 semester. The

purpose of the visit was primarily to enable the P.I. to develop his expertise in Pattern Recognition, which is expected to be of greater benefit to both the P.I. and to ONR as the Probability and Statistics Program changes its emphasis towards Computational Decision Making.

8. The P.I. presented a series of tutorial seminars of interest to working scientists and engineers while visiting the Naval Surface Warfare Center, and the University of Stellenbosch. The titles of these seminars were as follows: "Introduction to the Kalman Filter", "Simulated Annealing", "JPEG Image Compression", "Fast Fourier Transforms of Real-Time Data ","Independent Component Analysis", "Fingerprint Image Enhancement", "The Chirp z-Transform", "The Unscented Kalman Filter", "The Moving Fast Fourier Transform Algorithm", and "Image Compression Using Wavelets"

3. Collaborations and Research Visits

The P.I. paid two extended visits to the Naval Surface Warfare Center, Dahlgren, VA (summer 2002 and summer 2004) to perform work on this grant. These visits amounted to a total of 17 weeks.

Collaborations established at NSWC include:

1. **Bryan Freeman** (G33): non-magnetic determination of true north using gyroscopes; invention of a new approach for laser guided weapon guidance that minimizes the total active laser target designation time.
2. **Ron Gross** (G33): development of Matlab demonstration suite for wavelet algorithms.
3. **Jack Shuler** (G33): development of Matlab software to optimize RF absorption characteristics of multilayer rubber surfaces.
4. **Marilyn Rudzinsky** (T44): wavelet smoothing techniques for clutter rejection involving temporal techniques in the infrared (CRITTIR).
5. **Addison Jump**: development of parameterizations for orthonormal wavelets (during the early days of the project).

The ONR Probability and Statistics Program supporting this project was changing its emphasis towards the area of Computational Decision Making. Therefore, in October 2002 the decision was made, with the support of the program officer, to change the research direction of the project accordingly. The P.I. applied to UNC-Charlotte to take sabbatical leave for Fall 2003 in order to improve his expertise in the area of Pattern Recognition. The P.I. visited the University of Stellenbosch, South Africa for a period of 6 months on sabbatical leave to perform work on this grant. The University of Stellenbosch provided full financial assistance towards accommodation costs. Collaborations that were initially developed during the P.I.'s previous project for ONR were further expanded. The following two collaborations were of particular importance, since they are both experts in pattern recognition:

1. **Dr. Johan Du Preez**, Professor of Signal Processing in the Department of Electrical Engineering at the University of Stellenbosch.

2. **Dr. Ben Herbst**, Professor of Applied Mathematics at the University of Stellenbosch.

A collaboration between the P.I. and **Dr. Y.P. Kakad**, Professor of Electrical and Computer Engineering at the University of North Carolina-Charlotte has been established. Dr. Kakad provides expertise concerning the hardware implementation of algorithms developed by the P.I. In addition, Dr. Kakad has expertise in Kalman filtering and inertial guidance systems, and this was applied in our collaboration with Bryan Freeman of NSWC that resulted in a new tracking algorithm for laser guided weapons. Several publications produced by this collaboration are listed later.

4. Students:

The following graduate students performed work on this project:
1. **Amit Shukla**, (M.S. Electrical Engineering student), performed mathematical derivations, implemented algorithms in software, and co-published an article with the P.I. Also developed aspects of hardware implementations.
2. **Tejaswini Gadicherla**, (M.S. Electrical Engineering student), developed software programs.
3. **Brian C. Johnson**, (B.S. Electrical Engineering Technology Senior), wrote software to test the P.I.'s algorithms.
4. **Parinita Rane**, (M.S. Computer Science student), performed derivations and wrote software.

5. Publications:

The following refereed journal and conference papers were published by the P.I. during the period of the grant:

1. B.G. Sherlock, Y.P. Kakad and B.J. Freeman, "A Target Tracking Algorithm that Reduces Designation Time for Laser Guided Weapons", *SPIE Defense and Security Symposium (DSS 2005)*, Orlando, Florida, March 2005.
2. B.G. Sherlock, Y.P. Kakad and A. Shukla, "Rapid update of odd DCT and DST for real-time signal processing", *SPIE Defense and Security Symposium (DSS 2005)*, Orlando, Florida, March 2005.
3. B.W. Frazier, J. Roche, R.K. Tyson, Y.P. Kakad and B.G. Sherlock, "Robust Control of an Adaptive Optical System", *Journal of Engineering Manufacture (Proceedings of the Institution of Mechanical Engineers Part B)*, Vol. 218, 2004, pp. 353-358.
4. T. Shaw, Y. P. Kakad, and B. G. Sherlock: "Neural Network Control of a Shape Memory Alloy Wire Actuated Robot Hand", *20th International Conference on CAD/CAM, Robotics and Factories of the Future (CARS&FOF 2004)*, San Christobal, Venezuela, July 2004. Selected for publication in book, ISBN 980-12-0787-6, pp. 428-437.

5. B.G. Sherlock and Y.P. Kakad, "Transform Domain Technique for Windowing the DCT and DST", *Journal of the Franklin Institute*, Vol. 339, January 2002, pp. 111-120.

6. B.G. Sherlock and Y.P. Kakad, "MATLAB Programs for Generating Orthonormal Wavelets", *2nd WSEAS International Conference on Signal, Speech and Image Processing (ICOSSIP 2002)*, Skiathos, Greece, September 2002.

7. B.G. Sherlock and Y.P. Kakad, "MATLAB Programs for Generating Orthonormal Wavelets", selected for publication in book *Advances in Multimedia, Video and Signal Processing Systems*, World Scientific and Engineering Society Press, 2002, ISBN 960-8052-72-6, pp. 204-208.

8. B.W. Frazier, R.K. Tyson, Y.P. Kakad and B.G. Sherlock, "Robust Control of an Adaptive Optics System Using H_∞ Method", *18th Annual Conference on CAD/CAM, Robotics and Factories of the Future (CARS&FOF'2002)*, Porto, Portugal, July 2002, pp. 555-561.

6. Presentations:

1. "Introduction to the Kalman Filter", tutorial seminar presented at the Naval Surface Warfare Center, Dahlgren, VA, June 25, 2004.

2. "Simulated Annealing", tutorial seminar presented at the Naval Surface Warfare Center, Dahlgren, VA, July 13, 2004.

3. "JPEG Image Compression", tutorial seminar presented at the Naval Surface Warfare Center, Dahlgren, VA, July 15, 2004.

4. "Fast Fourier Transforms of Real-Time Data ", tutorial seminar presented at the Naval Surface Warfare Center, Dahlgren, VA, July 22, 2004.

5. "Independent Component Analysis", tutorial seminar presented at the Naval Surface Warfare Center, Dahlgren, VA, July 20, 2004.

6. "Introduction to Fingerprint Image Processing and Fingerprint Image Enhancement", tutorial seminar presented at the Naval Surface Warfare Center, Dahlgren, VA, July 27, 2004.

7. "The Chirp z-Transform", tutorial seminar presented at the Naval Surface Warfare Center, Dahlgren, VA, August 3, 2004.

8. "The Unscented Kalman Filter", tutorial seminar presented at the Naval Surface Warfare Center, Dahlgren, VA, August 5, 2004.

9. "Introduction to the Kalman Filter". Three-hour tutorial presentation given at the Department of Applied Mathematics, University of Stellenbosch on October 15, 2003. Derived the Kalman filter equations in full detail from first principles, and introduced extensions to the Kalman filtering concept (Extended Kalman filter, Unscented Kalman Filter and Particle Filters).

10. "Simulated Annealing: Theory and Implementation", given at the Department of Applied Mathematics, University of Stellenbosch, August 2003.

11. Invited seminar entitled "Fingerprint Image Enhancement", given at the Department of Applied Mathematics, University of Stellenbosch, South Africa, August 4, 2002.

12. "Independent Component Analysis", given at the Naval Surface Warfare Center, Dahlgren, VA, June 10, 2002.

13. "The Moving Fast Fourier Transform Algorithm", given at the Naval Surface Warfare Center, Dahlgren, VA, June 12, 2002.
14. "The Chirp Z-Transform", given at the Naval Surface Warfare Center, Dahlgren, VA, June 19, 2002.
15. "JPEG Image Compression", given at the Naval Surface Warfare Center, Dahlgren, VA, June 21, 2002.
16. "Introduction to Simulated Annealing", given at the Naval Surface Warfare Center, Dahlgren, VA, June 25, 2002.
17. "Image Compression Using Wavelets", given at the Naval Surface Warfare Center, Dahlgren, VA, June 27, 2002.
18. "Image Compression Using Wavelets", given at the Department of Applied Mathematics, University of Stellenbosch, South Africa, July 25, 2002.
19. "Independent Component Analysis", given at the Department of Applied Mathematics, University of Stellenbosch, South Africa, August 1, 2002.